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Method of modulation and demodulation of a digital signal, in particular in a frequency band affected by flat fading, associated modulator and demodulator

The invention relates to the modulation of digital signals on a given useful frequency band, in particular the FM band, and the associated demodulation.

The last two decades have seen the appearance of audio storage means of excellent quality. This sound quality has been obtained, in particular, by storing not only the analog signal but its digital version. Thus, digital compact discs have surpassed existing radio broadcasting in terms of quality of the sound reproduced. This difference in sound quality is so important that it has given rise to a modification of the market: listeners preferring to listen to audio compact discs than radio.

Several digital broadcasting standards have thus been developed in order to improve the sound quality of the broadcast signal: DAB, DRM etc. DAB (Digital Audio Broadcasting), developed to eventually replace FM broadcasting, offers the advantage of great robustness to the multipath phenomenon is especially well suited to mobile reception. However, it presents several major drawbacks, the cost of deployment in particular for a network with wide geographical coverage, the need to create a bundle of programs or to partner with other radio broadcasters and finally a relatively high cost of the receivers.

The analog FM band being saturated, the first idea for increasing the local coverage capacity was to use low-power transmitters in DRM digital mode either in medium wave or at the top of the shortwave band (26 MHz) that is scarcely employed by international radio broadcasters. To do this, the AM band, listened to less and less on account of the mediocre quality of

the sound reproduced, had to be revalued. The solution proposed by DRM radio broadcasting is the transmission of the signal in digital form in the AM band. The sound quality of the reception of a digital broadcasting system using the AM band according to the DRM standard is thereby considerably improved: sound quality close to that of analog FM broadcasting or even superior under reception conditions subject to multipaths with possibilities of data services associated or otherwise with the audio program.

As all broadcasting operators know, the resources allocated to radio broadcasting are limited. The AM band, even used in digital, will quickly be saturated. Moreover, though the use of these AM bands for local coverage is turning out to be very effective to date, it is very difficult to eliminate any risk of ionospheric propagation that might create undesirable interference in other zones of coverage, even very distant ones. It would therefore be beneficial to profit from the existing techniques of broadcasting in the AM band and to transpose them to the FM band.

Unfortunately, the FM band presents a major drawback in respect of digital transmission. It is a harsh environment subject to multipaths. Hence, the main problem of the FM band is a propagation problem called spatial fading or flat fading. This fading of the signal is related to a phenomenon of local interference and depends on the place where the receiver is located and on the frequency.

The present invention makes it possible to alleviate these drawbacks by using the principle that the fading is different depending on the frequency used. The digital signal is divided into several blocks, each being transmitted on the band in a separate channel from the transmission channels of the other blocks. Thus, when the signal fads on a frequency, only one

block is affected: there is no abrupt loss of information.

A subject of the invention is a method of modulating a digital signal of width L in frequency on a given useful frequency band comprising the following steps:

- a separation of the digital signal into N blocks b_n ($1 \leq n \leq N$),
- a splitting of the given useful frequency band into N contiguous parts P_n,
- a definition of channels C_n, of width l_n in frequency, lying within an associated part P_n,
- a distributing of each block of digital signals b_n over the associated channel C_n.

This method of modulation can define the channels C_n by taking account of a predetermined minimum distance between these channels. This minimum distance between the channels can be determined as a function of the number N of channels, of their width l_n so that a minority of channels are affected by the phenomenon of flat fading.

Another subject of the invention is the modulator of digital signals over a given useful frequency band implementing this method of modulation and comprising:

- means of separation of the digital signal into N blocks b_n ($1 \leq n \leq N$),
- means of splitting of the given useful frequency band into N contiguous parts P_n,
- means of definition of channels C_n of width l_n in frequency, lying within an associated part P_n,
- means of distributing of each block of digital signals b_n over the associated channel C_n.

Furthermore, the invention proposes a demodulator of digital signals conveyed on a given useful frequency band by a transmitter comprising a modulator as described above. The modulator comprises:

- means of scanning of the N channels C_n making it possible to read the N blocks b_n of signals distributed over these channels,
- means of recombination of the N blocks read $\hat{b}_n$ in the N channels C_n into a digital signal $\hat{s}[m]$.

Moreover, the subject of the invention is a transmitter of digital signals on a given useful frequency band comprising at least one transmission chain comprising a modulator such as that described hereinabove. The transmission chain comprises an error corrector coder conveying the coded digital signal to the modulator.

According to the invention, there is also proposed a receiver of digital signals conveyed on a given useful frequency band by this transmitter. The receiver comprises a demodulator such as described hereinabove and a decoder associated with the error corrector coder of the transmitter receiving the digital signal recombined $\hat{s}[m]$ by the demodulator.

In a variant of the invention is proposed the use of the transmitter and of the receiver described hereinabove for the transmission of digital signals in the FM band.

The characteristics and advantages of the invention will become more clearly apparent on reading the description, given by way of example, and of the appended figures which represent:

- Figure 1, a general frequency representation of the use of the given useful frequency band during the transmission of a digital signal according to the invention,
- Figure 2, a frequency representation of an example of use of the FM band during the transmission of a digital signal on two distinct channels according to the invention,

- Figure 3, a general frequency representation of the use of the given useful frequency band during the transmission of several digital signals according to the invention,
- Figure 4, a simplified diagram of a modulator of digital signals on a given useful frequency band according to the invention,
- Figure 5, a simplified diagram of a demodulator of digital signals conveyed on a given useful frequency band according to the invention,
- Figure 6, a simplified diagram of a transmitter of digital signals on a given useful frequency band comprising several transmission chains according to the invention,
- Figure 7, a simplified diagram of a receiver of digital signals conveyed on a given useful frequency band according to the invention.

Figure 1 represents the use of the given useful frequency band B_u by the digital signal during its transmission. The method of modulation according to the invention divides the digital signal s[m] into N blocks b_1 to b_N. The digital signal s[m] having a frequency width equal to L, each of the N blocks $\{b_n\}_{(1 \leq n \leq N)}$ has a respective frequency width l_n such that their sum is equal to that of the signal s[m]: $\sum_{n=1}^{N} l_n = L$. The given useful frequency band is itself divided into N parts P_n. In each of these parts P_n is defined a channel C_n of width l_n in which the signal of the associated block b_n will be distributed.

The widths l_n of the channels C_n may all be different ($l_1 \neq l_2 \neq \ldots \neq l_N$), equal ($l_1 = l_2 = \ldots = l_N$) or else some of them may be equal and others different ($l_f = l_g = \ldots = l_h, \ldots l_i = l_j = \ldots = l_k$ and $l_a \neq l_b \neq \ldots \neq l_c l_e \neq l_f \neq \ldots \neq l_g$, $1 \leq a,b,c,f,g,h,i,j,k \leq N$). If the N channels C_n are of identical widths, their width

is equal to an Nth of the width of the digital signal $L: l_n = L/N,\ \forall\ 1 \leq n \leq N$.

During definition of the channels C_n, the latter are separated. This separation is equal to a predetermined minimum distance. The minimum distance between the channels C_i and C_{i+1} may be different from the predetermined distance between the channels C_j and C_{j+1}. The minimum distance may be determined as a function of the number N of channels $\{C_n\}$, of their width l_n, and of the mean width of the frequency band affected by the phenomenon of flat fading. This minimum distance allows a predetermined maximum number of blocks $\{b_n\}$ to be affected by the phenomenon of flat fading. Thus, the loss of information is not abrupt. This maximum number may be determined such that a minority of channels C_n/blocks b_n is affected.

This method of modulation may therefore be used for the transmission on all frequency bands liable to be affected by the phenomenon of flat fading, in particular the FM band.

Figure 2 represents the use of the FM band B_u by the digital signal during its transmission. In the case illustrated by Figure 2, the modulation proposed is a simplified version of the method of modulation according to the invention. Specifically, the method of modulation divides the digital signal s[m] into two blocks b_1 and b_2. The digital signal s[m] having a frequency width equal to L, each of the two blocks b_1 and b_2 has a respective frequency width l_1 and l_2 such that their sum is equal to that of the signal s[m]: $l_1 + l_2 = L$. In the case of Figure 2, the widths of the two blocks b_1 and b_2 are equal $l_1 = l_2 = l = L/2$. The FM band is itself divided into two parts P1 and P2. In each of these parts P1 and P2 is defined a channel C_1, respectively C_2, of width L in which the signal of the associated block b_1, respectively b_2, will be

distributed. In order to transpose the DRM standard to the FM band, the blocks b_1 and b_2 may be of $l = 20$ KHz in width.

The frequency band, regardless of its use may be occupied by several digital signals originating from one or more operators. For example, several operators share the FM band to broadcast radiophonic transmissions.

Figure 3 illustrates this sharing of the FM band by several digital signals. Each of the Q signals $\{s^q[m]\}_{(1 \leq q \leq Q)}$ is divided into two blocks b^q_1 and b^q_2. As in Figure 2, the FM band is split into two parts P_1 and P_2. In each of these parts P_1 and P_2 are defined Q channels C^q_1, respectively C^q_2, of width l. In each channel C^q_n is distributed the signal of the associated block b^q_n. When one or more minimum distances are determined for the channels $\{C^1_n\}$, on which the blocks b^1_n of a signal $s^1[m]$ are distributed, they are identical for the channels $\{C^q_n\}$, on which the blocks b^q_n of all the signals $s^q[m]$ are distributed.

The number of parts P_n is not limited to two, but can depend on the mean width of the frequency band affected by the flat fading. For example, the given useful frequency band may be divided into part having a width equal to the mean width of the frequency band affected by the flat fading.

The width of the channels C^q_n is not necessarily identical in all the parts P_n. However, the width of all the channels C^q_n of a given part P_i is identical $(l^1_i=l^2_i=\ldots=l^Q_i)$.

Figure 4 proposes a simplified block diagram of the modulator according to the invention. The modulator 30 receives a digital signal s[m] at the input of its means of separation 31 of the digital signal into N

blocks b_n. The modulator 30 receives the characteristics of the given useful frequency band B_u in which the signal s[m] is to be transmitted. The knowledge through these characteristics of the given useful frequency band B_u makes it possible for the splitting means 32 to divide the band B_u into N parts P_n. The characteristics of the N parts P_n are conveyed by the splitting means 32 to the means of definition 33. The means of definition 33 determines the channel C_n of width l_n corresponding to each of the N parts P_n. To each channel C_n there corresponds a block b_n of like width l_n. Thus, the N blocks of signals b_n at the output of the means of separation and the characteristics of the N channels C_n at the output of the means of definition 33 are conveyed to the input of the distributing means 34. The distributing means 34 assign each block b_n to the associated channel C_n making it possible to obtain a distribution of the signal over the given useful frequency band B_u, as represented by Figure 1.

Figure 5 proposes a representation in the form of a simplified block diagram of a demodulator 80 of digital signals conveyed on a given useful frequency band by a transmitter comprising a modulator such as that illustrated by Figure 4. The signal received r[m] is of the form of that represented by Figure 1. This signal received r[m] is conveyed to means of scanning 81 of the N channels C_n. The means of scanning 81 extract from each of these N channels C_n the block $\hat{b}_n$ received corresponding to the block b_n transmitted. The N blocks $\hat{b}_n$ read are conveyed to the means of recombination 82. These means of recombination 82 reconstitute on the basis of the N blocks $\hat{b}_n$ read from the N channels C_n a digital signal $\hat{s}$[m] corresponding to the signal s[m] transmitted in the form of the N blocks b_n.

Figure 6 illustrates a transmitter according to the invention. The transmitter proposed comprises Q transmission chains, one per signal to be transmitted in the given useful frequency band. Each chain receives the data to be transmitted $d^q[m]$. These data $d^q[m]$ may, for example, be coded by an error corrector code 10^q. The coded data $c^q[m]$ may be mixed, in particular, with the aid of an interleaver 20^q. The signal $s^q[m]$ is obtained at the output of all the preprocessings of the transmission chain, such as the error corrector coding, the interleaving, etc, is then processed by the modulator 30^q according to the invention.

If the transmitter (such as that illustrated by Figure 6) comprises, several transmission chains, the blocks b^q_n of each of the Q transmission chains may be conveyed to a multiplexer 40 linked to an antenna 50. When the useful band of given frequencies is divided into two parts, the distribution of the signals transmitted by the antenna 50 may be represented such as in Figure 3.

If the transmitter comprises just one transmission chain, the modulator 30 can be linked directly to the antenna 50. The distributing of the signals by the various transmitters over the given useful frequency band may be performed by allocating to the transmitters using this band: the number N of parts, the minimum distance or distances between the channels and a frequency, on the basis of all of which the transmitter will be capable of defining by virtue of the means of definition 33 of the modulator 30 the channels on which it can transmit without interfering with the other transmitters sharing this band.

Figure 7 illustrates a receiver according to the invention. This receiver of digital signals is suitable for the reception of digital signals conveyed on a given useful frequency band by a transmitter such as that of Figure 6.

The antenna 60 conveys the signals received on the given useful frequency band to selection means 70. These selection means convey to the demodulator 80 the signal received r[m] and the characteristics of the channels C^q_n comprising the blocks b^q_n of the signal $s^q[m]$ that the receiver must reproduce. The demodulator 80 thus recombines the blocks $\hat{b}^q_n$ read from the N channels C^q_n into a signal $\hat{s}^q[m]$ corresponding to the signal $\hat{s}^q[m]$ transmitted.

If the transmitter comprises an interleaver 20, the receiver will comprise an associated deinterleaver 90 so as to reinstate the demodulated signal $\hat{s}^q[m]$. The deinterleaved signal $\hat{c}^q[m]$ is conveyed to a decoder 100 when the transmitter also comprises a channel coder 10. The decoder 100 is associated with the channel coder 20. At the output of the decoder 100, the receiver provides the data $\hat{d}^q[m]$ corresponding to the data transmitted $d^q[m]$.

The receiver can also be envisaged with a decoder 100 and without deinterleaver 90, when the transmitter comprises a coder 10 but no interleaver 20. The output of the demodulator 80 is then linked directly to the input of the decoder 100.

The assembly of devices described by Figures 4 to 7 may be used for digital transmission in the FM band, in particular for radio broadcasting. The sound quality thus obtained is akin to that of digital audio storage means, such as that of the compact disc. Furthermore, the FM band has the advantage of allowing the broadcasting of local programs: regional music programs, local retransmission of concerts, etc.